62-3-5

SSD-TDR-62-45

NOX

DEVELOPMENT AND EVALUATION OF THE USAF BALLISTIC TEST EVALUATION SYSTEM FOR SOLID ROCKET PROPELLANTS

TECHNICAL DOCUMENTARY REPORT NO. SSD-TDR-62-45

April 1962

6593d TEST GROUP (DEVELOPMENT)
Edwards, California
AIR FORCE SPACE SYSTEM DIVISION
Air Force System Command
United States Air Force

SSD-TDR-62-45
April 1962

DEVELOPMENT AND EVALUATION OF THE USAF BALLISTIC TEST EVALUATION SYSTEM FOR SOLID ROCKET PROPELLANTS

Author

HAROLD W. GALE, 1/Lt., USAF

This report has been reviewed and approved.

HAROLD W. NORTON
Colonel, USAF
Commander 6593d Test Group (Dev)

NOTICES

FOREWORD

This technical report has been prepared to present the development and current status of the USAF Ballistic Test Evaluation System (BATES). The total development was conducted by the Solid Systems Branch of the 6593d Test Group (Development) at Edwards AFB, California. The solid propellant industry survey and initial design phases were conducted by Mr. W. C. Andrepont who was replaced as Project Engineer in September 1960, by Lt. H. W. Gale. The technical cooperation and assistance of Dr. L. M. Brown of Rohm and Haas, Chairman of the JANAF Static Test Panel Working Group on Scale Testing, is sincerely appreciated.

ABSTRACT

This technical documentary report presents the method of development and current status of the USAF Ballistic Test Evaluation System (BATES) for solid propellants. The objective of the program is to develop a reproducible, accurate, ballistic evaluation system for solid propellants of interest to the Air Force. Particular attention is centered on an accuracy level of 0.5 percent or better on specific impulse (Isp). Evaluation of new propellants by their manufacturers has resulted in a multiplicity of definitions and mathematical correction factors which obscure actual performance results and complicate qualitative comparison of competitive propellants. Therefore, a program has been conducted at Edwards AFB by the 6593d Test Group (Dev) to establish an in-house Air Force capability for standard performance evaluation of propellants.

An industry survey was made to determine desirable standard motor system parameters and prevailing practice. The best features were subsequently adopted in the motor and system design as far as possible.

Twelve firings of two propellants have been made for motor and system evaluation purposes. All objectives were successfully achieved or exceeded. Calibration firings are being made to establish the confidence level and accuracy of the system prior to evaluation of industry propellants.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS DIAGRAMS AND FIRING TRACES

PHOTOGRAPHS

DEVELOPMENT AND EVALUATION
OF THE
U. S. A. F. BALLISTIC TEST EVALUATION SYSTEM
FOR
SOLID ROCKET PROPELLANTS

INTRODUCTION.

The objective of the BATES program is to obtain standardized, reproducible, and accurate ballistic data on applicable solid rocket propellants from rocket firings. The operational mode will employ a standard rocket motor and standardized precision instrumentation. This will allow more accurate evaluation and comparison of solid rocket propellants available to the Air Force.

Background.

The solid propellant rocket motor industry encompasses numerous contractors, each of which has diverse testing facilities, test procedures, and propellant evaluation motors. The diversity of industry test methods has produced a situation such that it is difficult, if not impossible, to compare propellant data from the various sources. Efforts to obtain standardized ballistic data on propellants in the past have been limited to defining standardized terminology and data reduction procedures by the applicable military specifications, such as MIL-R-25532A. However, standard data acquisition procedures and standard motors have not yet been established. It has been conclusively demonstrated that appreciable discrepancies in comparative performance data between various propellant systems have gone undetected for considerable lengths of time. For example, discrepancies in the order of five to six seconds of specific impulse have gone undetected for periods in excess of a year. A discrepancy of this magnitude in the third stage of a three-stage ballistic missile could cause a range error of 200 - 250 miles.

Therefore, a ballistic test evaluation system or standard propellant evaluation development program was initiated in March 1960.

Approach.

Preliminary research was conducted to determine the most desirable features of the standard test motors, data acquisition systems, and data reduction procedures used by several major rocket companies. Participation in the efforts of the Working Group on Scale Testing of the JANAF Static Test Panel has been continued as well in order to insure maximum compatibility with industry accepted practice. Finally, a preliminary analysis of error sources within the system was made with a view to eliminating or minimizing as many as possible.

a. Standard Motors.

The industry standard motors were compared and a set of near optimum ballistic parameters selected for the BATES Motor. The major parameters are described below.

1. Short duration, two to ten seconds, to minimize heat loss and nozzle erosion.

2. Large throat size to minimize nozzle erosion effects.

3. Large port to throat ratio, about seven, to minimize grain erosive burning.

4. Little or no insulation and liner to avoid unwanted mass contributions to the flow.

5. Neutral thrust-time trace at 1000 psia chamber pressure to minimize thrust coefficient corrections and tailoff.

6. Nominal expansion to ambient pressure at operating conditions. Slightly below optimum area ratio is preferred to guarantee full nozzle flow attachment throughout the firing time.

7. Shockless reproducible ignition to insure proper function of automatic data acquisition systems and minimum igniter contribution.

8. Cylindrically perforated grain configuration to eliminate geometry effects.

9. High propellant weight to minimize scale factors with larger motors. Low cost per motor, minimum shipping costs, and ease of handling were included as desirable features of a standard motor.

The initial motor choice was an exisiting JATO motor since hardware would be available. Unfortunately, no available motor met more than one or two of the requirements. The best features of many industry "standard motors" were then selected and combined. The resultant motor (Figure 1 and Table 1) has undergone mechanical checkout firings with only minor changes for convenience in handling. Propellant grain geometry and chamber pressure are constant for all propellants. Expansion ratio is slightly less than optimum for each propellant in order to avoid flow separation at the nozzle exit plane. No liner or insulation of any sort is used or necessary for most propellants. A basket igniter is used to insure shockless ignition and complete igniter engergy release prior to ignition of the grain. Igniter charge weight is varied to suit the propellant needs. The chamber is made of 347 annealed stainless steel to permit repeated firings of the same motor without insulation. Carbon steel is used in the nozzle portion with a graphite throat insert.

A "cartridge cast" propellant grain was selected in preference to the conventional case-bonded grain for several reasons. Low cost, lightweight, casting fixtures (Figure 2), could replace the heavy, expensive, chambers in casting and shipping of the propellant, with obvious savings. Furthermore, the motor alignment on the thrust stand need not be disturbed between firings since removal of the expended cartridge leaves a clean chamber after firing.

b. <u>Data Acquisition and Reduction.</u>

The choice of data acquisition and reduction systems was considered to be at least as important as the motor design. The ideal system should have digital readout of all information channels directly to automatic plotting and integration machines of very high accuracy. The exisiting system featured FM to tape and oscillograph readout followed by semiautomatic data reduction. Conversion to full automatic acquisition and reduction was not

feasible within the scope of the funding. Therefore, a system analysis of error sources was made in the hopes of minimizing the purchase of new equipment. It was found that a high accuracy (.25%) thrust stand feeding a ballistic thrust integrator (.1%) would suffice. Weight measurement of the propellant would need to be within .1 pound. Thus only two new items were necessary, the thrust stand and the ballistic integrator. The anticipated accuracy was established to be about .4% at the one sigma limit with 95% confidence level based on an eight sample group. The group size was set at ten in order to provide for sizing of the nozzle and igniter in preliminary firings.

The definition of specific impulse, action time, and other parameters were taken directly from recommendations of the JANAF Working Group on Scale Testing, with the minor exception that specific impulse is reported at a 15° exit half angle in the interest of the fewest possible purely mathematical corrections. The reported specific impulse is defined as the thrust integral, between chamber pressure limits of 100 psia, divided by the total weight of propellant expended. Correction is made from operating pressures to 1000 psia chamber pressure with optimum expansion to sea level, 14.7 psia.

Correlation of information from the industry indicated that a major difficulty in comparing test results between companies resulted from mathematical "correction factors" applied to the firing results in order to improve the reported specific impulse (Isp). Several companies are achieving two to five percent Isp improvement in this manner. Typical techniques range from "sorting" of firing results to eliminate low values or arbitrarily defining a computational Isp, but reporting it as standard, to simply correcting the nozzle exit half angle from 15° to 0°. The BATES motor was designed to minimize or eliminate the areas, such as insulation loss, for which questionable corrections had been made. As a result, the only mathematical correction used is for actual firing pressure and nozzle expansion to 1000 psia chamber pressure with optimal expansion to sea level for 15° nozzle exit half angle. No other correction of any sort is foreseen. Checkout firings to date support the initial decision.

Test Program.

The development and test program was divided in three parts.

a. Mechanical checkout of the motor

b. Calibration of the system

c. Evaluation of industry propellant

The first phase was intended to reveal any motor structural flaws and establish the performance characteristics of the motor. It was successfully completed in January 1962. The second phase will establish the accuracy and reproducibility limits of the system. The final phase will test industry propellants and result in published findings.

The test setup for phase one was made with available low accuracy equipment. Typically, the stand was a modified JATO stand aligned to ± 5 degrees against a compression load cell of 10K capacity and lightly preloaded. The instrumentation was of similar quality. In the twelve firings, eight at the Rocket Research Laboratories and four at Rohm and Haas, four materials for nozzle inserts, three materials for cartridge tubes, three types of igniter, and two burn rates of propellant were included (Table II). Photographs of the motor prior to firings, nozzle inlet after firing, a fired cartridge tube, thrust and pressure traces, and motor case temperature traces are included in this report.

The motor firings to date have demonstrated several unusual characteristics of the design not apparent from Table II. Nozzle erosion is largely confined to the turning surface at the throat of the nozzle and independent of area ratio at onset and termination of erosion along the axis. This is attributed to angular acceleration of the boundary layer in that area, since the predicted detachment and reattachment lags are observed. Erosion occurs in the HLM graphite by loss of material between the grains. The nozzle insert becomes free floating during firing, and unless restrained, will be found lying in the head end of the chamber after firing. Correlation of the high speed motion pictures with the pressure and thrust traces showed the movement took place with a chamber pressure of about 50 psia at tailoff

and was not indicated on either pressure or thrust traces. A single 1/4" bolt inserted at the throat region has eliminated this feature (Figure 1). Transient thermal stresses in the nozzle and chamber were found to be quite large. A shrink fit of the insert to aft closure was sufficient to prevent damage to the nozzle, except in the single firing at Rocket Research Laboratories where a loose fit was used and the exit cone was lost. Thermal transients in the head and walls produced stresses about 50% of the superimposed pressure stresses in the chamber, apparent as a zero shift on the strain gage data during firing. Heat transfer in the nozzle and chamber was near expectations. Calculations of heat loss and film coefficients were based on the assumption that the temperature rise of the components was solely the result of convective heating and the temperature differential of surface to gas was constant at 5000°F:

$$Q = C_p M \Delta t = h_f A \Delta T \theta$$

$$Q = BTU \quad h_f = \frac{BTU}{ft^2 \, {}^\circ F \, sec}$$

$$C_p = \frac{BTU}{lb_m \, {}^\circ F} \quad A = ft^2$$

$$M = lb_m \quad \Delta T = (5,000)^\circ F$$

$$\Delta t = {}^\circ F \quad \theta = Sec$$

The heat flux rate in both sizes of nozzle was the same, .26 BTU/ ft^2 °F sec.), and the total heat transfer was also the same, 5,700 BTU, although the throat diameters were 1.7 and 2.26 inches respectively. Heat transfer to the motor head was nearly the same, 1100 BTU and 920 BTU, with heat flux rates of .05 and .09 BTU/(ft^2 °F sec) respectively. Order of magnitude calculations indicate about 10,000 BTU are used in heating inert parts, and assuming 2600 BTU/lb of propellant, about 5% of the energy of the propellant is used for this purpose. This heat loss is comparable with most industry standard motors and appears to be essentially constant for state of the art propellants.

Igniter effects on the ballistic trace were very small, even where substantial ignition delay occurred. Thrust and pressure traces, Figures 5 and 6, follow delays of 15, 11 and .15 seconds between igniter firing and grain ignition. The low thrust trace is apparently instrumentation error. The sharp drop in the same trace resulted from loss of the nozzle exit cone. The igniters causing the long delays were based on black powder. The third was a 15KS1000 JATO igniter. The igniter used by Rohm and Haas was a bag of pyrotechnic pellets used with nozzle plug for an ignition delay of .022 seconds. Future tests are planned for a variable charge igniter similar to the JATO igniter. The cartridge tubes, as noted in Table II, experienced no measureable weight loss. The materials were laminated sheets of the filler, bonded by epoxy or melamine resin, wound on a mandrel and oven-cured. Propellant bonding to the glass base was difficult, asbestos was satisfactory and paper base was good. Some delamination resulting in irregular burning on the grain ends was experienced with the glass base. A curious correspondence between relative amount of throat erosion and tube material has existed to date with paper apparently superior. A cost and performance tradeoff indicates the paper base grade is far superior.

The instrumentation was upgraded between successive firings until the reported specific impulse converged on the Rohm and Haas value within several seconds. At that time, the ratio of specific impulse based on thrust to specific impulse based on chamber pressure was 0.97. The pressure is within ±10% of average for 95% of the time. The measured total thrust impulse between 100 psia gates is above 99% of the total thrust impulse.

Conclusion on Motor Design.

a. The structural integrity of the motor design has been demonstrated

b. The ballistic characteristics of the motor are acceptable

c. Ignition is not a serious problem

d. An uninsulated cartridge loaded motor will perform with reasonably low heat loss.

Future Plans.

a. Substantial progress has been made under Phase B. The thrust stand with dead weight calibrator, Photo 5, has been received and installed with the ballistic integrator in an isolated, hardwired, system. Calibration firings are in progress.

b. It is estimated that 30 state of the art propellants will be tested per year. Eventual plans include test of future high energy exotic propellants.

REFERENCES

1. "Space Technology," edited by H.S. Seifert, Wiley Publishing CO., 1959.

2. "Thermal Stress Transients in a Flat Slab," I. Vigness and E.W. Clements, U.S. NRL Project 62R05-19B, Tech Memo No. 179, November 1961.

3. "An Equation for Estimating the Energy Required for Ignition of a Solid Propellant Rocket," E.L. Lawrence, NAVORD Report 6660, June 1959.

4. "Calibration and Control of Ballistic Data Recording and Assessment," Sunflower Ordnance Works.

5. "Evaluation of Propellants for the Second Stage of the Polaris A-3 IRBM," C.F. Nokes, Jr, and A.F. Domal, AEDC-TN-61-110, Aug 61.

6. "Quarterly Progress Report on Chemical and Propellant Processing," Rohm and Haas Co., Reports No. P-60-21 and P-60-7.

TABLE I

Propellant weight (approximate)	68 lbs.
Liner and insulation	None
Motor weight	271 lbs.
Chamber pressure	1,000 psia
Expansion area ratio	Optimum
Nozzle Exit Half Angle	15^{o}
Igniter	15KS1000 JATO or U.S. Flare 4010
Grain Dimensions:	length - 20 inches O.D. - 11.75 inches I.D. - 8 inches
Grain configuration	Neutral burning C.P.
Port/throat	15

TABLE II

BATES CHECKOUT FIRINGS

Firing Number	Tube Wt Before & After	Tube Material	Initial Throat Diameter	Nozzle Erosion	Nozzle Material	Action Time	Average Pressure	$^1Isp_f$ 1000/S.L. 15°	Comments
1-C1	4.39 4.38	* Paper	2.161	.017	HLM85	2.71	1073	♦ 236	C-Fired at Rohm & Haas 1-Rohm & Haas 112_{cb}
1-C2	4.55 4.55	** Asbestos	2.161	.017	ATJ	2.87	1007	♦ 211	2-Rohm & Haas 112_{cc}
1-C3	4.47 4144	Paper	2.160	.015	ATJ	2.89	982	100%	Tubes-Taylor Fiber Co *-Grade XX **-Grade AA ***-Grade C5
1-C4	5.81 5.73	*** Fiberglass	2.159	.027	-	2.96	946	100%	HLM Nozzle Material Manufactured by Great
1-1	4.67 4.54	Asbestos	2.034	.019	HLM80	2.53	1180	230	Lakes Carbon Co.
1-2	4.61 4.60	Asbestos	2.257	.010	♦ HLM80	2.82	890	100%	100%-Isp_F ±1 Sec of Rohm & Haas
1-3	4.55 4.50	Paper	2.257	.023	HLM85	2.98	890	-	
1-4	4.49 4.49	Asbestos	2.220	.031	HLM85	2.94	924	100%	
2-1	5.68 5.65	Fiberglass	1.699	.034	HLM85	4.03	1130	♦ 204	
2-2	4.51 4.50	Paper	1.700	.028	HLM80	3.96	1180	235	
2-3	4.51 4.50	Paper	1.680	.027	HLM85	4.03	1171	100%	
2-4	5.35 5.25	Fiberglass	1.947	.002	HLM85	4.34	892	100%	

♦1-1 remachined

♦Lost Exit Cone

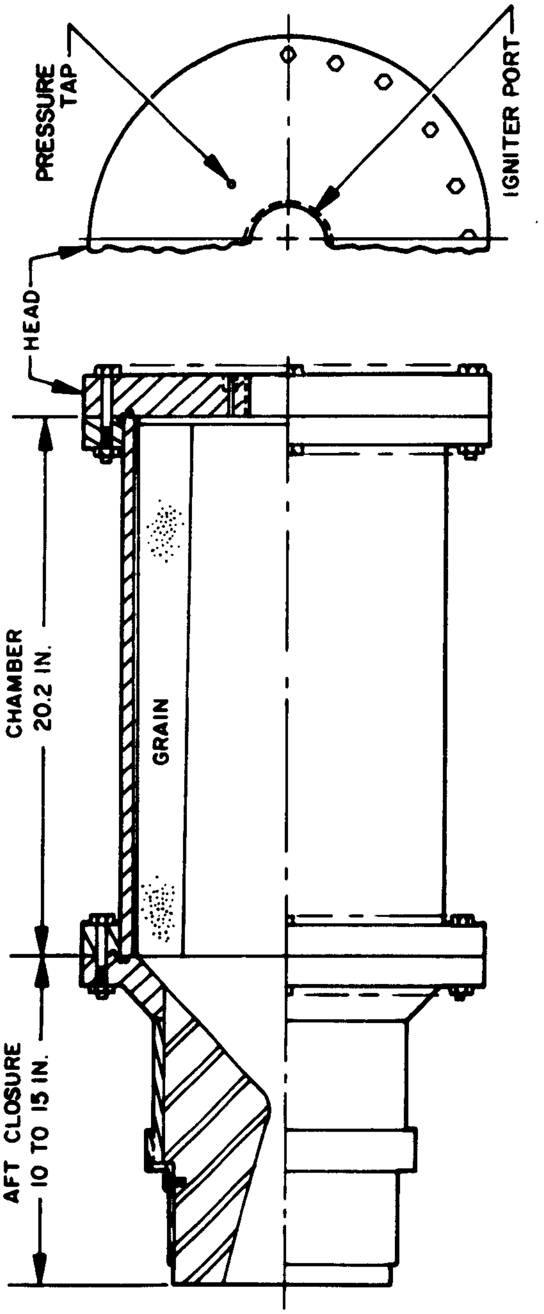

Figure 1. BATES Motor.

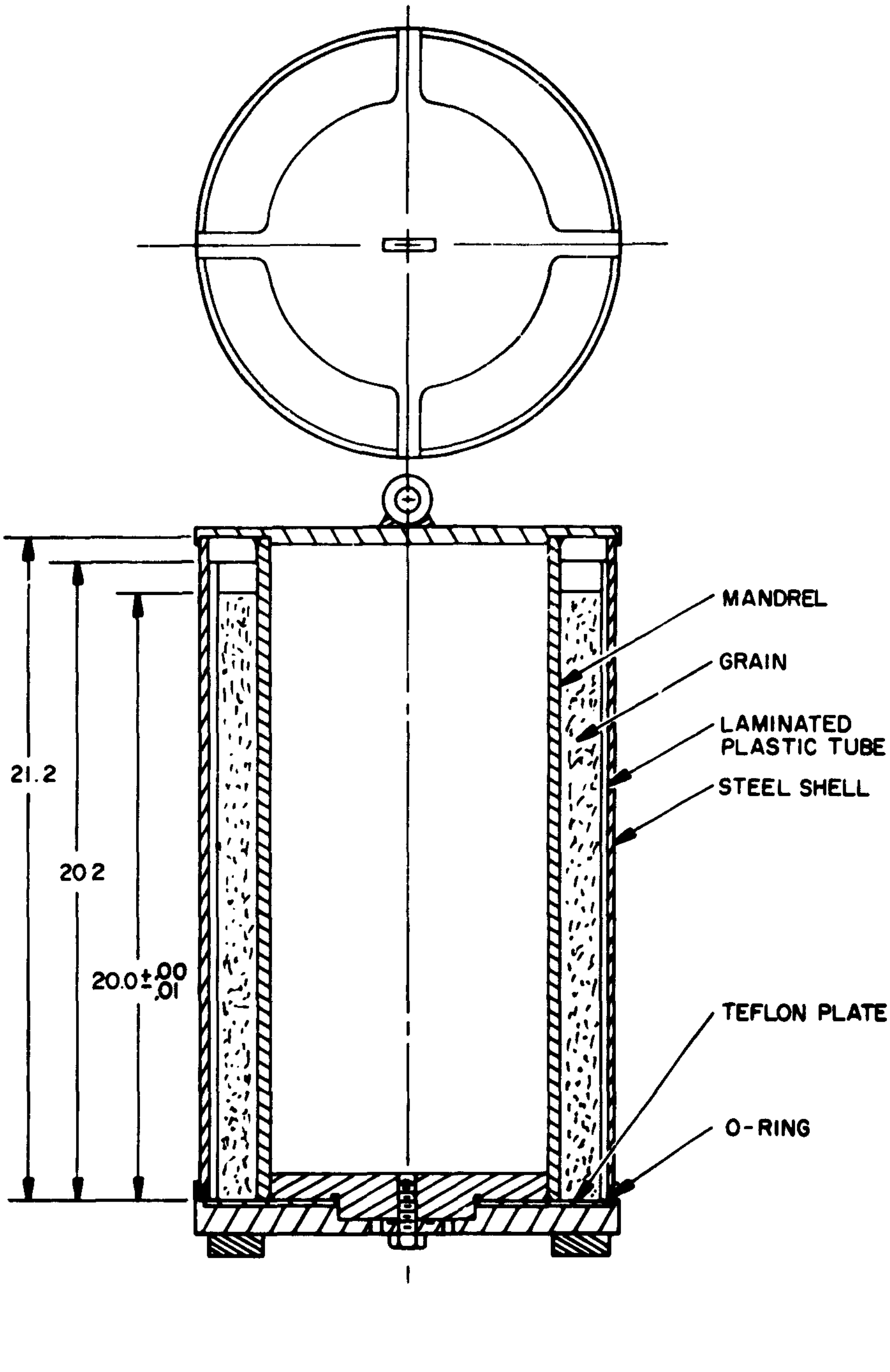

Figure 2. Casting Fixture Assembly BATES Motor.

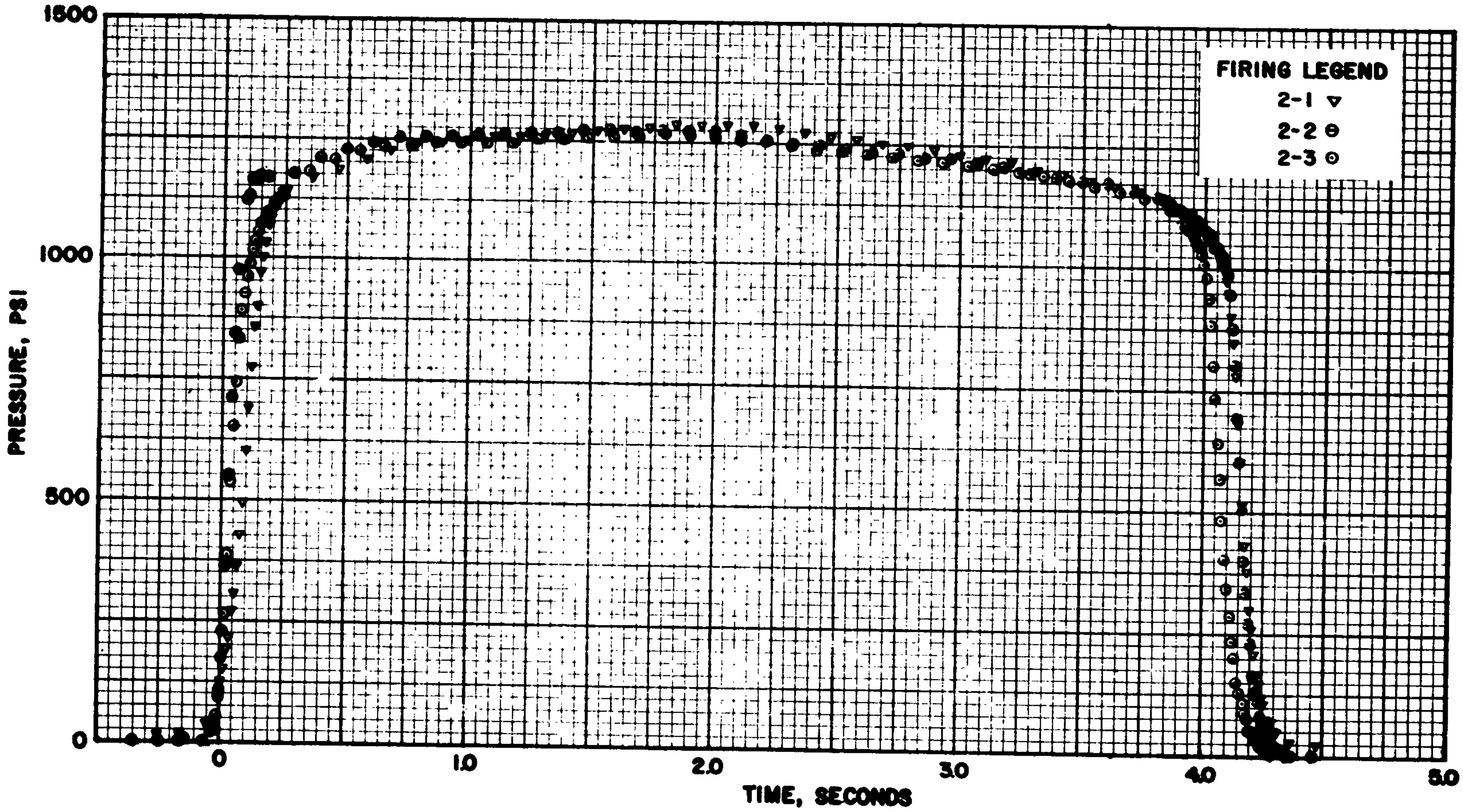

Figure 3. BATES Pressure vs. Time.

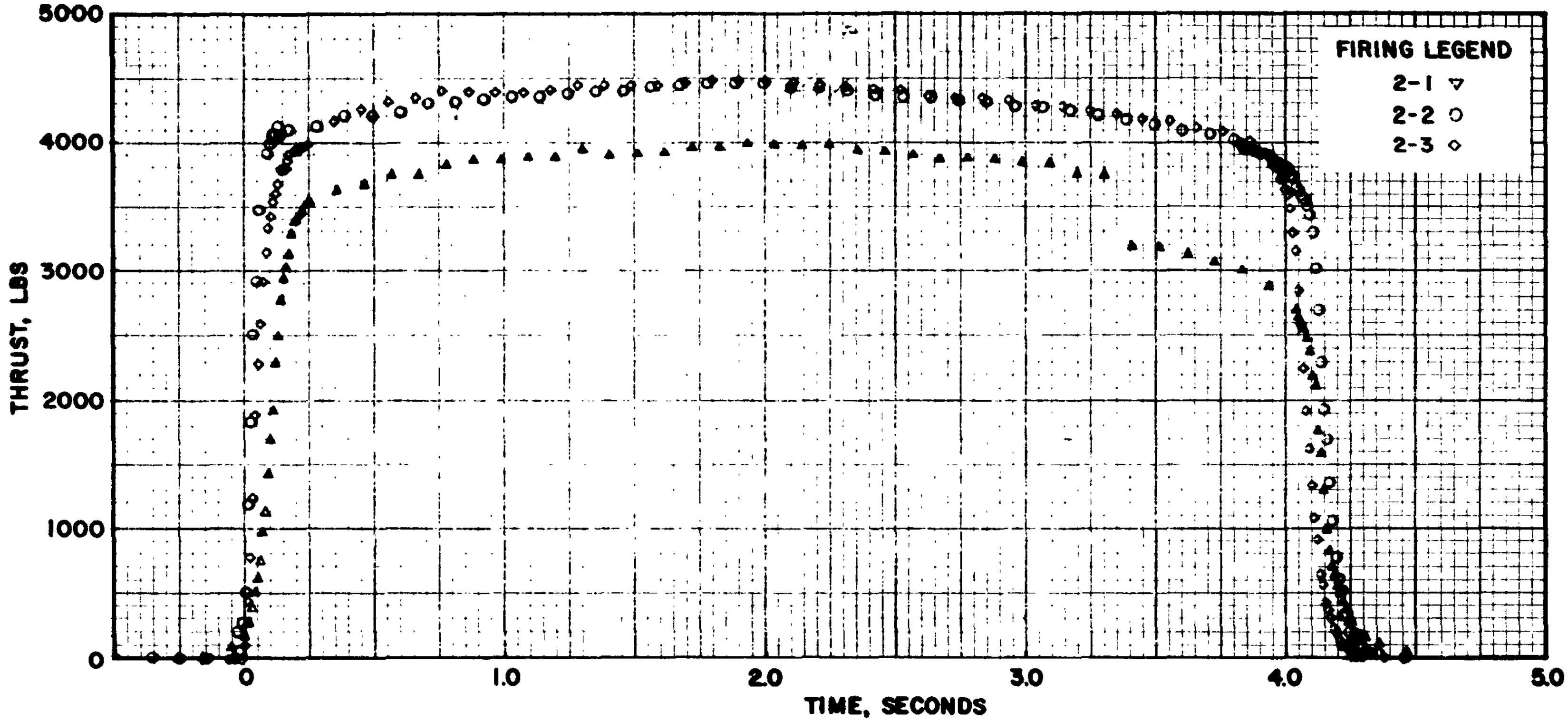

Figure 4. BATES Thrust vs. Time.

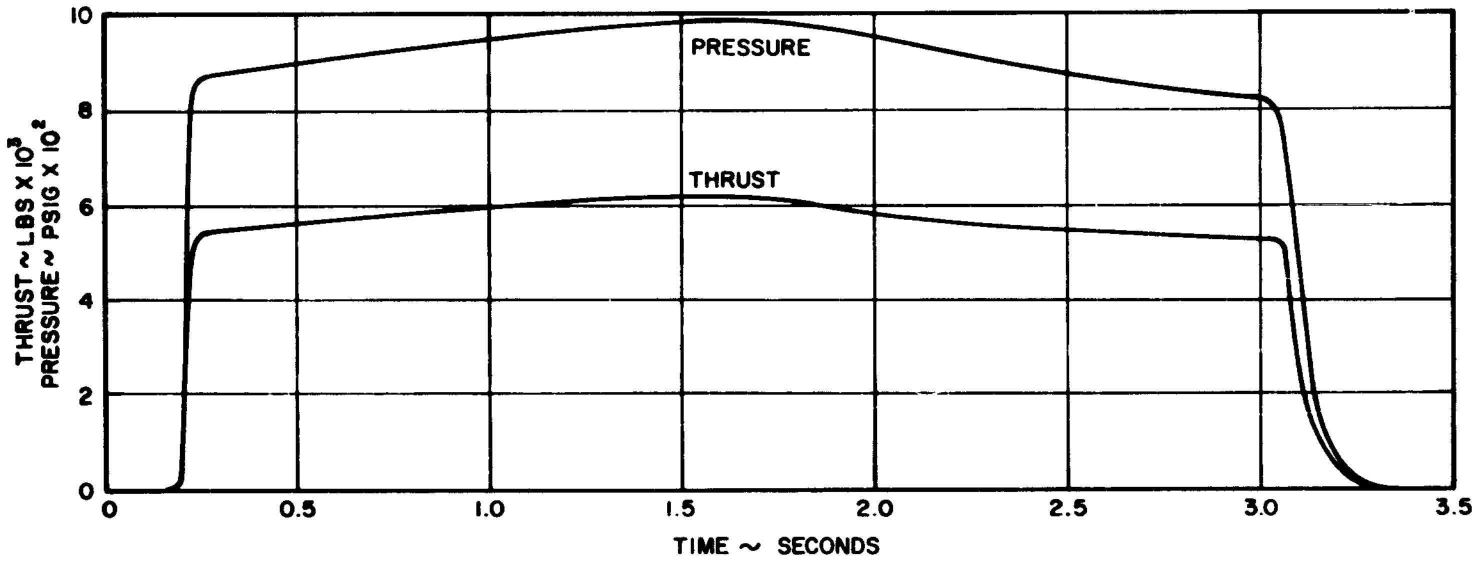

Figure 5. BATES Project 3059-1 Run 7 16 Jan 62 Firing 1-4.

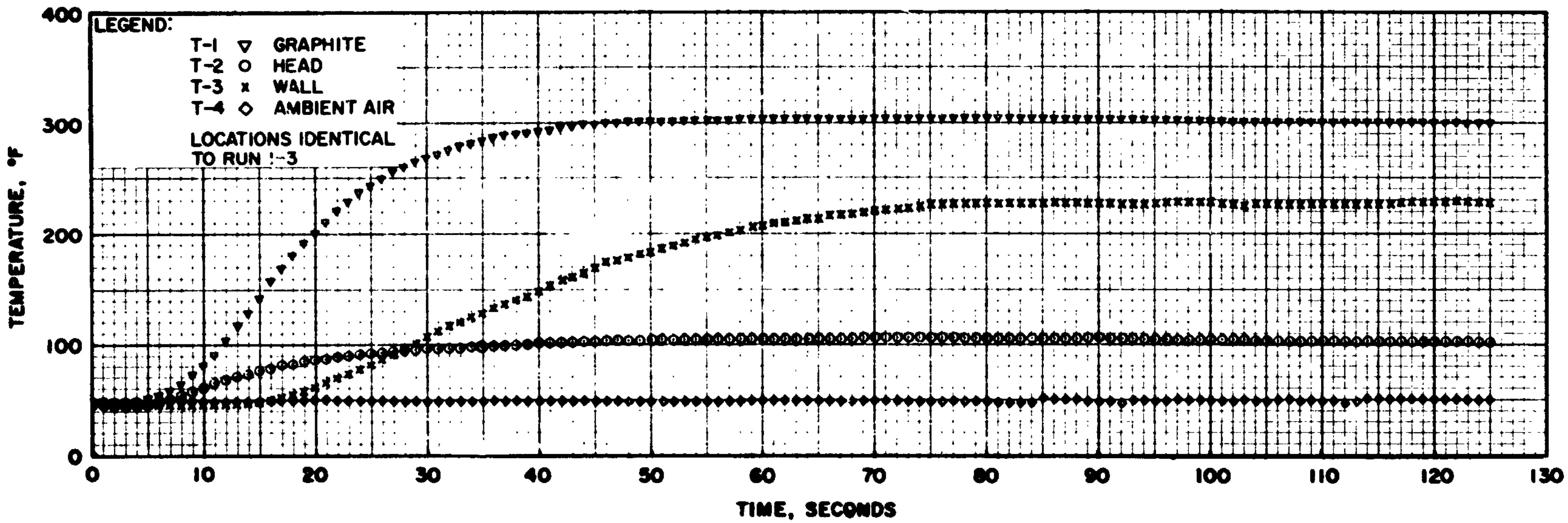

Figure 6. BATES Run No. 2-3 Temperature Traces.

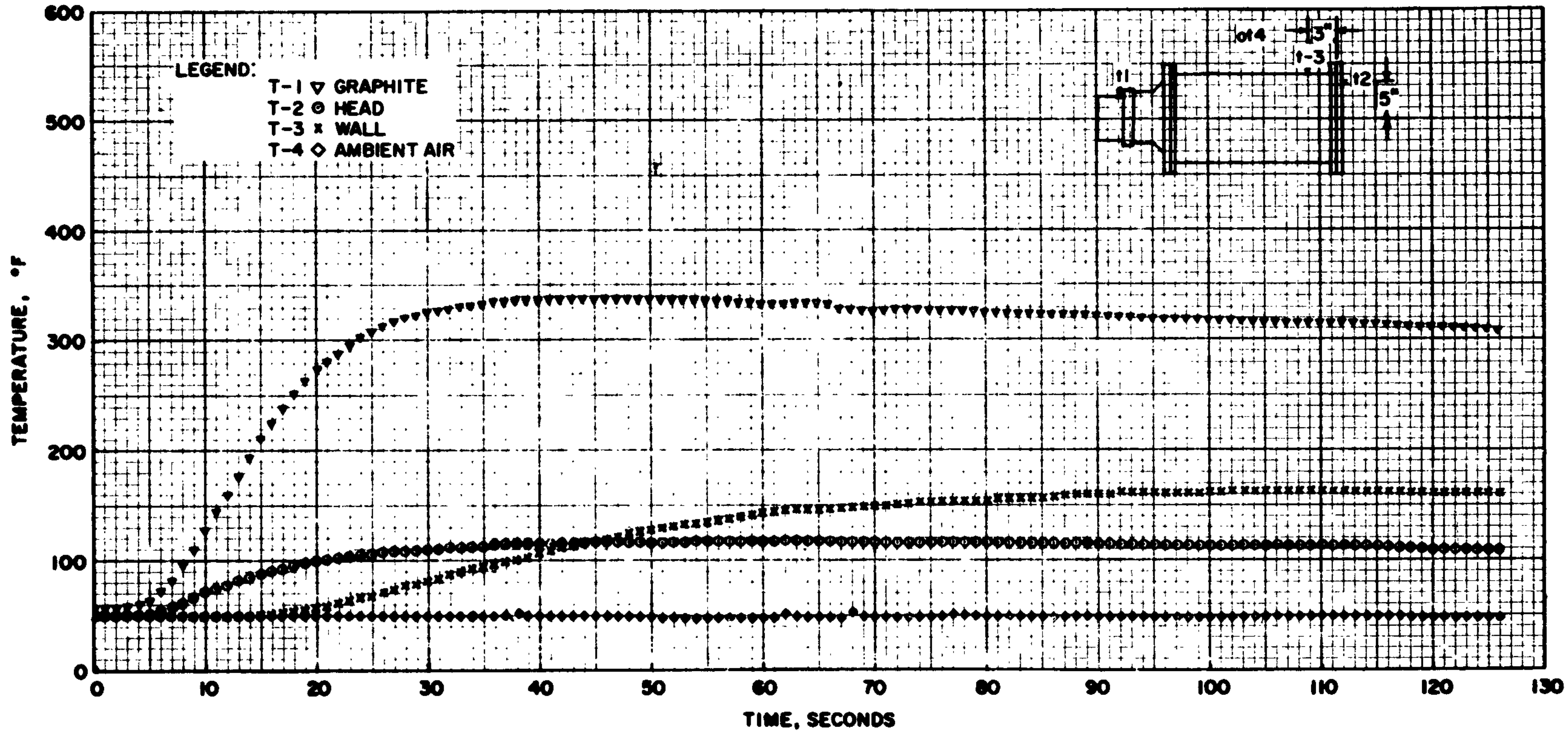

Figure 7. BATES Run No. 1-3 Temperature Traces.

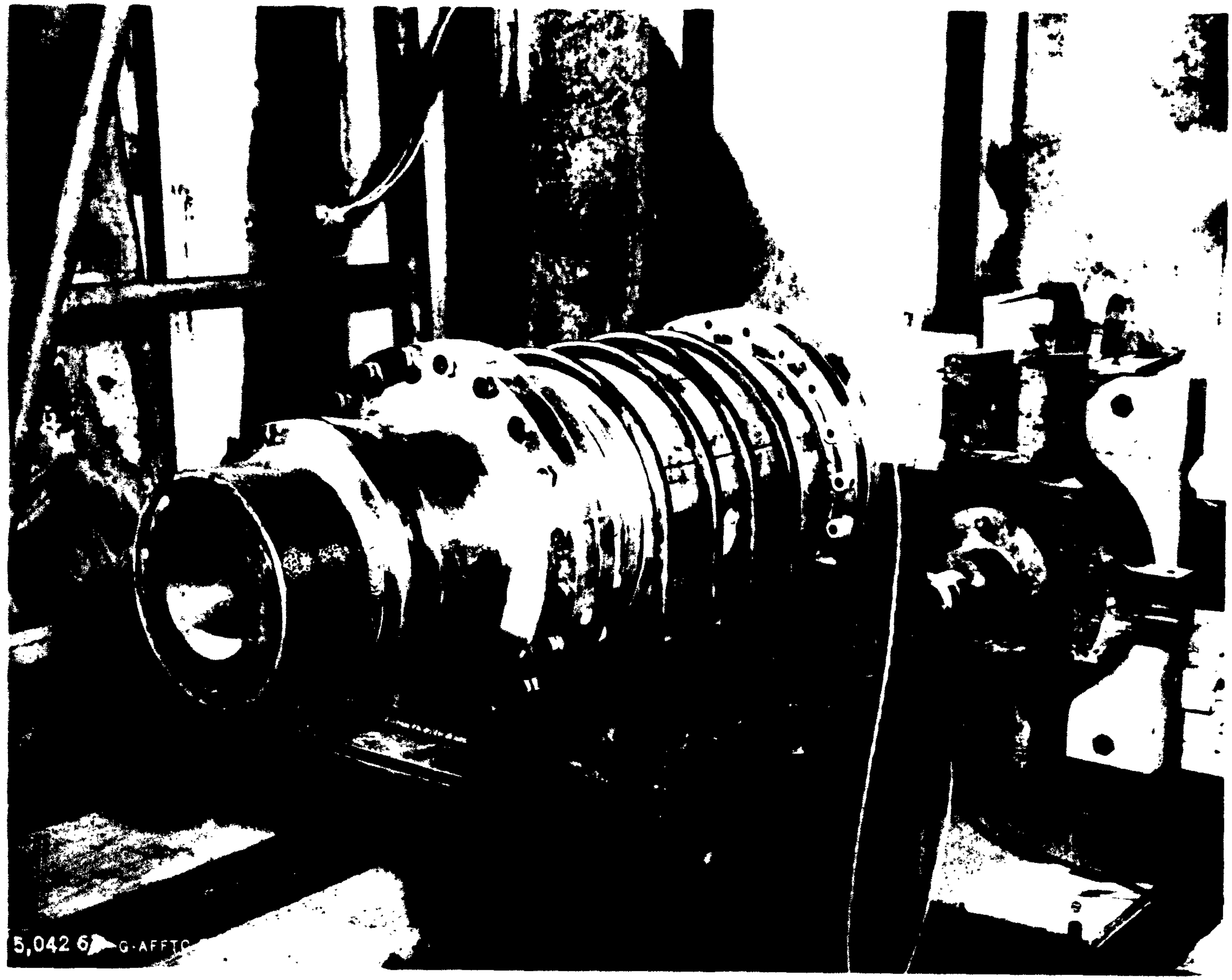

Photo 1. Bates Motor on Heavyweight Test Stand

Photo 2. Bates Nozzle Inlet-Fired Nozzle

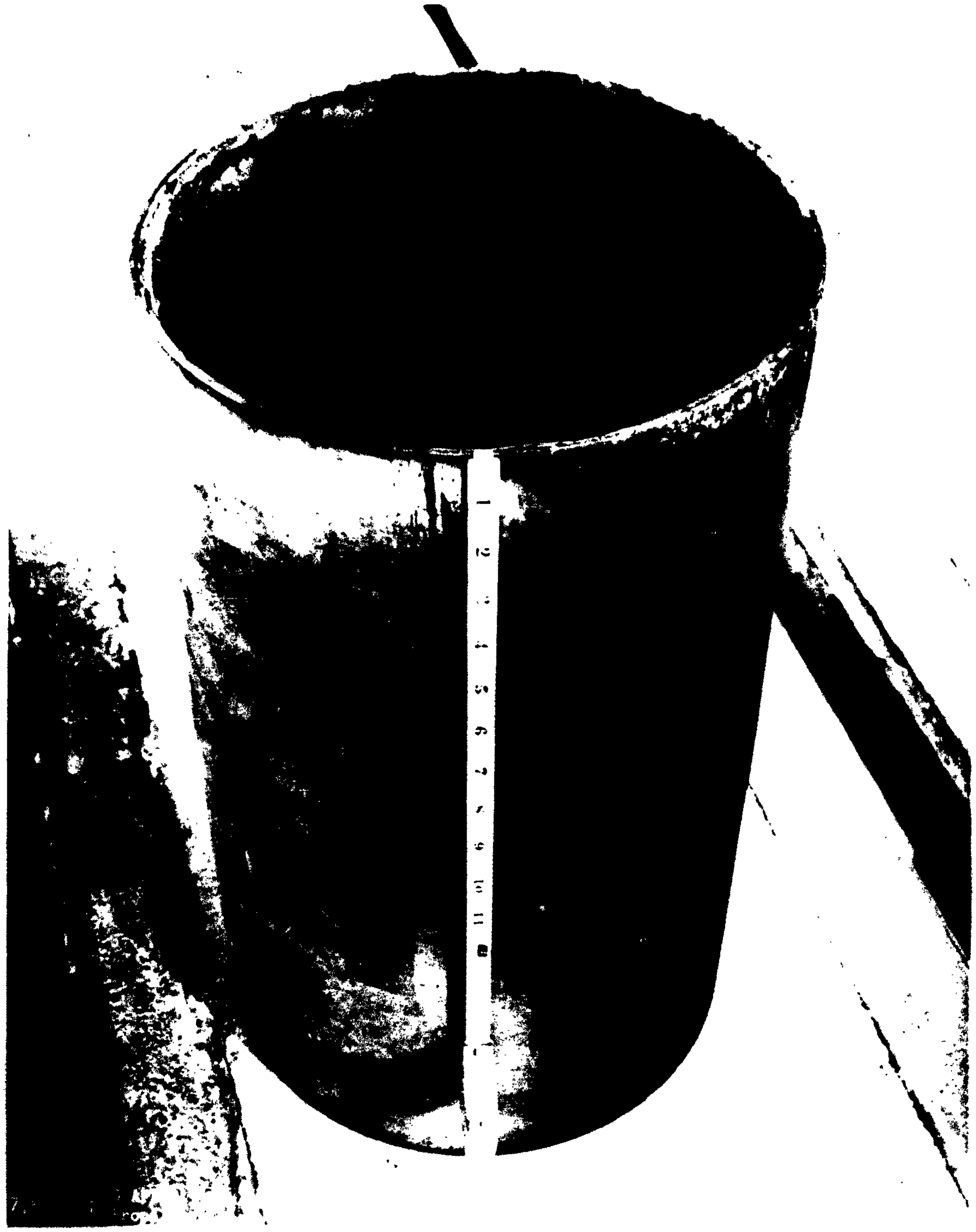

Photo 3. Bates Propellant Cartridge Tube-Fired Condition
(Paper Base Material Taylor Fiber Co. Grade XX).

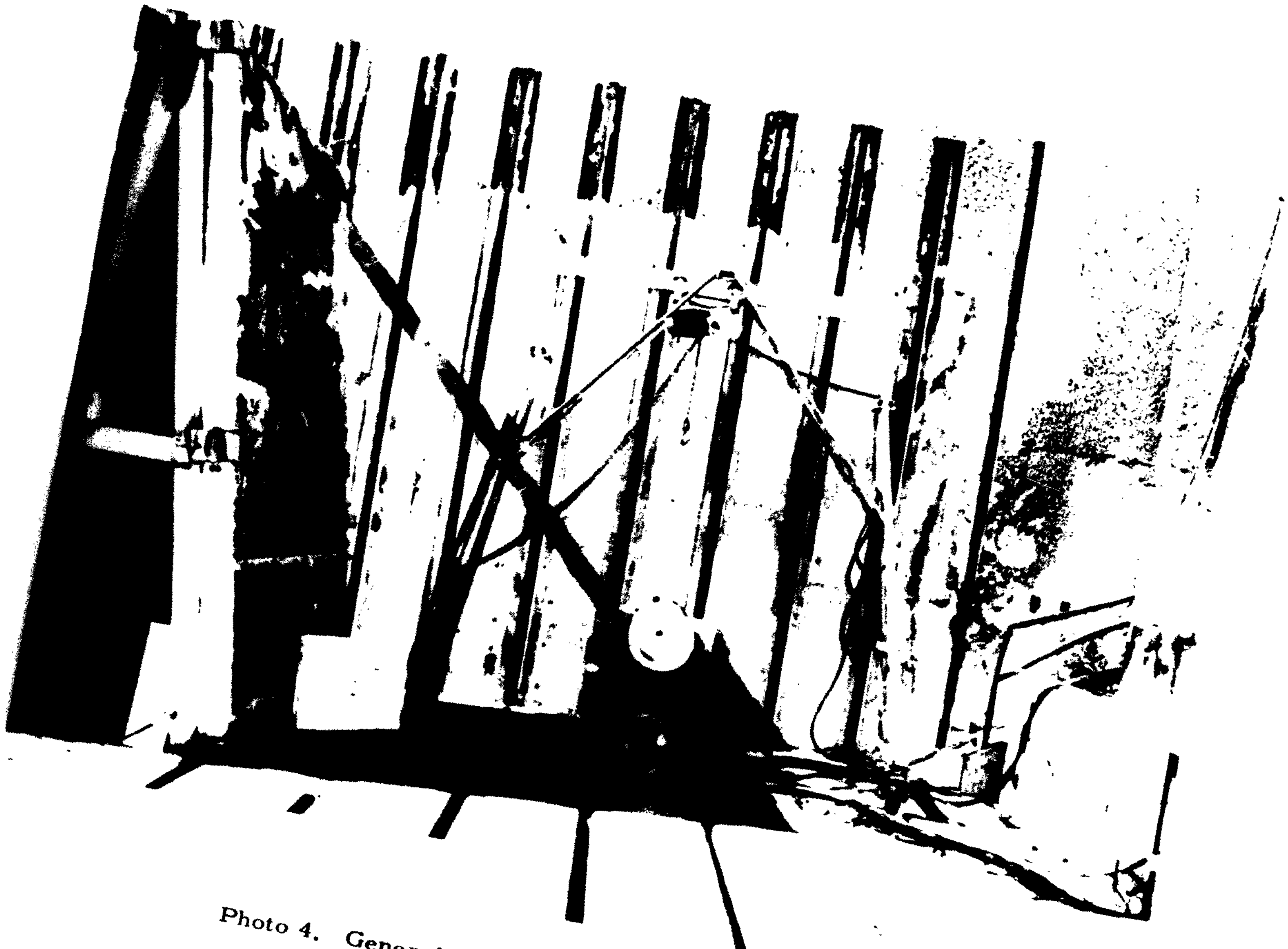

Photo 4. General Test Area Bates Checkout Firings

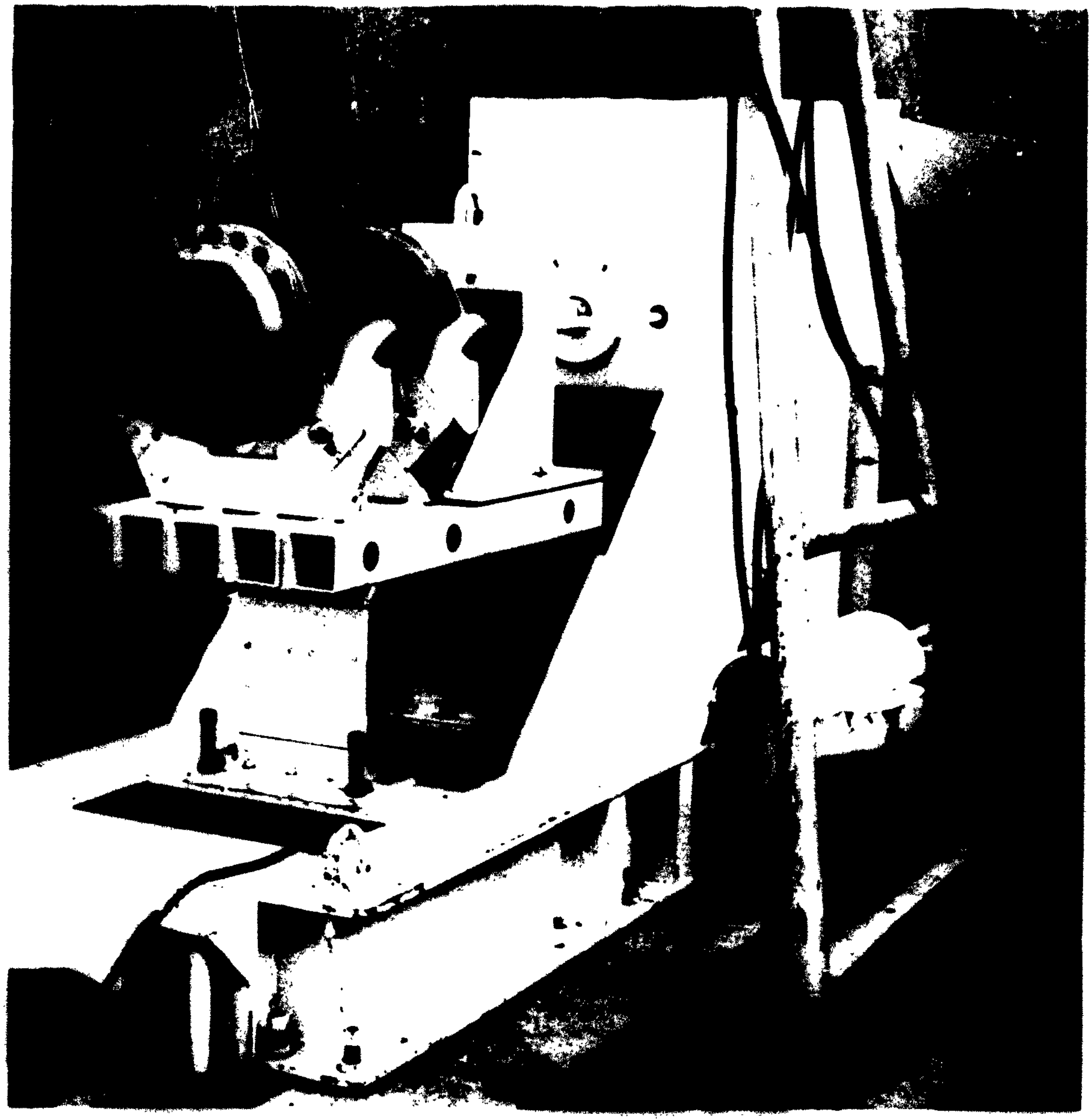

Photo 5. Bates High Accuracy Thrust Stand

DISTRIBUTION LIST

Solid Propellant Information Agency distribution list dated May 1962 NOTE: 6593d T.G. (Dev) will make distribution.	150
ASTIA	10
Space Systems Division DCLMT (Mrs. Densmore) AF Unit Post Office Los Angeles 45, Calif	1
Air Force Flight Test Center FTOOT Edwards Air Force Base, Calif	10
6593d Test Group (Dev) Edwards, Calif	
DGS	50
DGLP	30
Total	251

Space Systems Division, 6593d Test Group (Development), Edwards, Calif.
SSD-TDR-62-45. DEVELOPMENT AND EVALUATION OF THE USAF BALLISTIC TEST EVALUATION SYSTEM FOR SOLID ROCKET PROPELLANTS.
Final report, April 1962, 27 p. incl illus., tables.

Unclassified Report

Design considerations for a solid rocket propellant evaluation motor are presented. Motor design and development are discussed. Initial firing data indicates successful completion of all objectives for a high reproducibility of motor performance.

1. Solid Rocket Motor
2. Propellant Evaluation

I. AFSC Project 3059-1
II. H. W. Gale, 1/Lt, USAF
III. In ASTIA Collection

Space Systems Division, 6593d Test Group (Development), Edwards, Calif.
SSD-TDR-62-45. DEVELOPMENT AND EVALUATION OF THE USAF BALLISTIC TEST EVALUATION SYSTEM FOR SOLID ROCKET PROPELLANTS.
Final report, April 1962, 27 p. incl illus., tables.

Unclassified Report

Design considerations for a solid rocket propellant evaluation motor are presented. Motor design and development are discussed. Initial firing data indicates successful completion of all objectives for a high reproducibility of motor performance.

1. Solid Rocket Motor
2. Propellant Evaluation

I. AFSC Project 3059-1
II. H. W. Gale, 1/Lt, USAF
III. In ASTIA Collection

Space Systems Division, 6593d Test Group (Development), Edwards, Calif.
SSD-TDR-62-45. DEVELOPMENT AND EVALUATION OF THE USAF BALLISTIC TEST EVALUATION SYSTEM FOR SOLID ROCKET PROPELLANTS.
Final report, April 1962, 27 p. incl illus., tables.

Unclassified Report

Design considerations for a solid rocket propellant evaluation motor are presented. Motor design and development are discussed. Initial firing data indicates successful completion of all objectives for a high reproducibility of motor performance.

1. Solid Rocket Motor
2. Propellant Evaluation

I. AFSC Project 3059-1
II. H. W. Gale, 1/Lt, USAF
III. In ASTIA Collection

Space Systems Division, 6593d Test Group (Development), Edwards, Calif.
SSD-TDR-62-45. DEVELOPMENT AND EVALUATION OF THE USAF BALLISTIC TEST EVALUATION SYSTEM FOR SOLID ROCKET PROPELLANTS.
Final report, April 1962, 27 p. incl illus., tables.

Unclassified Report

Design considerations for a solid rocket propellant evaluation motor are presented. Motor design and development are discussed. Initial firing data indicates successful completion of all objectives for a high reproducibility of motor performance.

1. Solid Rocket Motor
2. Propellant Evaluation

I. AFSC Project 3059-1
II. H. W. Gale, 1/Lt, USAF
III. In ASTIA Collection